Long-term VHE γ-ray monitoring of bright blazars with a dedicated Cherenkov telescope

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Abstract: High-peaked BL Lacertae objects are a prime source population for studies with Cherenkov telescopes. It is obvious that monitoring observations of strong blazars are orthogonal to the mission of the larger Cherenkov telescopes, as H.E.S.S. and MAGIC with their discovery potential for new sources (luminosity function, redshift distribution). We propose to set up a Cherenkov telescope with low-cost but high performance design for robotic operation. The goal is to achieve long-term monitoring of bright blazars which will unravel the origin and nature of their variability. The telescope design is based on a technological upgrade of one of the former telescopes of the HEGRA collaboration on the Canarian Island La Palma (Spain). A first study is presented.

Introduction Since the termination of the HEGRA observations, the succeeding experiments MAGIC and H.E.S.S. have impressively extended the physical scope of gamma ray observations by detecting tens of formerly unknown gamma ray sources and analyzing their energy spectra and temporal behavior. This became possible by lowering the energy threshold from 700 GeV to less than 100 GeV and increasing at the same time the sensitivity by a factor of five.

To fully exploit the discovery potential of the improved sensitivity, the discovery of new, faint objects has become the major task for the new telescopes. A diversity of astrophysical source types such as pulsar wind nebulae, supernova remnants, microquasars, pulsars, radio galaxies, clusters of galaxies, gamma ray bursts, and blazars can be studied with these telescopes and limits their availability for monitoring purposes of well-known bright sources.

But there are strong reasons to make an effort for the continuous monitoring of the few exceptionally bright blazars. This can be achieved by operating a dedicated monitoring telescope of the HEGRA-type, referred to in the following as DWARF (Dedicated multiWavelength Agn Research Facility). The reasons are outlined in detail below.

Science case The variability of blazars, seen across the entire electromagnetic spectrum, arises from the dynamics of relativistic jets and the particle acceleration going on in them. The jets are launched in the vicinity of accreting supermassive black holes. Theoretical models predict variability arising from the interplay between jet expansion, particle injection, acceleration and cooling [1].

Long-term monitor observations of bright blazars are the key to obtain a solid data base for variability investigations.

An understanding of this variability will deepen our knowledge about

- the composition and generation of the jets, intimately connected to the physics of the ergosphere of rapidly spinning black holes embedded into the hot plasma from the accretion flow.

- the plasma physics responsible for highly efficient particle acceleration, bearing similarities to plasma physics of the interaction

between extremely intense laser beams and matter.

- the orbital modulation of jets due to binary black holes expected from galaxy merger models.

Assuming conservatively the performance of a single HEGRA-type telescope, long-term monitoring of at least the following blazars is possible: Mrk421, Mrk501, 1ES 2344+514, 1ES 1959+650, H 1426+428, PKS 2155-304. We emphasize that DWARF will run as a facility dedicated to these targets only, providing a maximum observation time for the program.

- Flux variations will be determined and compared with variability properties in other wavelength ranges.
- Hadronic emission processes and possible coincidences between VHE γ- and neutrino-emission will be investigated.
- The search for signatures of binary black hole systems from orbital modulation of VHE γ ray emission will be performed.

Furthermore, we seek to obtain know-how for the operation of future networks of Cherenkov telescopes (e.g. a monitoring array around the globe or CTA) or telescopes at inaccessible sites.

At least one of the proposed targets will be visible any time of the year. For calibration purposes, some time will be scheduled for observations of the Crab nebula, which is the brightest known VHE emitter with constant flux.

In detail the following investigations are planned:

- As a direct result of the measurements, the duty cycle, the baseline emission, and the power spectrum of flux variations will be determined and compared with variability properties in other wavelength ranges.
- The lightcurves will be interpreted using models for the nonthermal emission from relativistically expanding plasma jets.
- The black hole mass and accretion rate will be determined from the emission models. Estimates of the black hole mass from emission models, a possible orbital modulation, and the Magorrian relation (relating the black hole mass with the stellar bulge mass of the host galaxy) [3] will be compared.
- When flaring states will be discovered during the monitor program, MAGIC will issue a Target of Opportunity observation to obtain better time resolution.
- Correlating the arrival times of neutrinos detected by the neutrino telescope IceCube with simultaneous measurements of DWARF will allow to test the hypothesis that flares in blazar jets are connected to hadronic emission processes and thus to neutrino emission from these sources. [4, 5] The investigation proposed here is complete for both neutrino and gamma observations, and can therefore lead to conclusive results.
- The diffuse flux of escaping UHE cosmic rays obtained from AUGER or flux limits of neutrinos from IceCube, respectively, will be used to constrain models of UHE cosmic ray origin and large-scale magnetic fields.
- Multi-frequency observations together with the Metshovi Radio Observatory and the optical Tuorla Observatory are planned. The measurements will be correlated with INTEGRAL and GLAST results, when available. X-ray monitoring using the SWIFT and Suzaku facilities will be proposed.
- The most ambitious scientific goal of this proposal is the search for signatures of binary black hole systems from orbital modulation of VHE γ ray emission [6]. In case of a confirmation of the present hints in the temporal behaviour of Mrk501, gravitational wave templates could be computed with high accuracy to establish their discovery with LISA.

Technical setup At the Observatorio del Roque de los Muchachos (ORM), at the MAGIC site, the mount of the former HEGRA telescope CT3 now owned by the MAGIC collaboration is still operational. Basic support from the shift crew of MAGIC is guaranteed, though robotic operation is

the primary goal and necessary to reduce costs and man power demands. Furthermore, we seek to obtain know-how for the operation of future networks of Cherenkov telescopes. From the experience with the construction and operation of MAGIC or HEGRA, respectively, the proposing groups consider the planned focused approach (small number of experienced scientists) as optimal for achieving the project goals. The available automatic analysis package developed for MAGIC is modular and flexible, and can thus be used with minor changes for the DWARF project [7].

To complete the mount to a functional Cherenkov telescope, the following steps are necessary:

Camera For long-term observations stability of the camera is a major criterion. To keep the systematic errors small good background estimation is mandatory. The only possibility for a synchronous determination of the background is the determination from the night-sky observed in the same field-of-view with the same instrument. To achieve this the observed position is moved out of the camera center which allows the estimation of the background from positions symmetric with respect to the camera center (so called wobble-mode). This observation mode increases the sensitivity by at least a factor of two because spending observation for dedicated background observations becomes obsolete, which also ensures a better time coverage of the observed sources. Having a camera large enough allowing more than one independent position for background estimation increases sensitivity further by better background statistics. This is the case if the source can be shifted 0.6°-0.7° out of the camera center. To decrease the dependence of the background measurement on the camera geometry, a camera layout as symmetric as possible will be chosen. Consequently a camera allowing for wobble-mode observations should be round and have a diameter of 4.5°-5.0° to completely contain shower images of events in the TeV energy range. To achieve this requirements a 313 pixel camera can be build based on the experience with HEGRA and MAGIC. Photomultipliers with 19 mm diameter and a quantum efficiency improved by 20% with respect to the CT3 system are considered.

They ensure a granularity which is enough to guarantee good results even below the flux peak energy. Each individual pixel has to be equipped with a preamplifier, an active high-voltage supply and control. If development of G-APDs ($QE \geq 50\%$) will be fast enough, respectively the price low enough, and their long term stability is proven well in time, their usage will be considered. For a transition time one of the old HEGRA cameras might be used. With a special coating (wavelength shifter) its quantum efficiency might be improved by 8%.

Camera support The camera chassis must be water tight. An automatic lid protecting the PMs at day-time will be installed. For further protection a plexi-glass window will be installed in the front of the camera. By over-coating the window with an anti-reflex layer of magnesium-fluoride a gain in transmission of 5% is expected. Each PM will be equipped with a light-guide. The current design will be improved by using a high reflectivity mirror-foil, to reach a reflectivity in the order of 98%. In total this will gain another $\sim$15$\%$ in light-collection efficiency compared to the CT3 system.

For this setup the camera holding has to be re-designed. An electric and optical shielding of the individual PMs is planned.

Data acquisition For the data acquisition system a low-cost hardware readout based on an analog ring buffer (Domino II/III), currently developed for the MAGIC II readout, will be used. The low power consumption will allow to include the digitization near the signal source which makes an analog signal transfer obsolete. The advantage is less pick-up noise and less signal dispersion. By high sampling rates (0.5 GHz-1.2 GHz), additional information about the pulse shape can be obtained. This increases the over-all sensitivity further, because the short integration time allows for almost perfect suppression of noise due to night-sky background photons. The estimated trigger-rate of the telescope is below 100 Hz (HEGRA: $<$10 Hz) which allows to use a low-cost industrial solution for readout of the system like USB2.0. As for the HEGRA telescopes, a simple multiplicity trigger is enough, but also a simple three-next-neighbors (closed package) could be programmed. Additional data reduction and preprocessing in the readout hardware or the readout computer is provided. Assuming conservatively storage of raw-data at a readout rate of 30 Hz the storage space needed is less than 250 GB/month or 3 TB/year.

On-site computing For on-site computing three standard PCs are needed. This includes readout and storage, preprocessing, and telescope control. The data will be transmitted as soon as possible after data taking via Internet to the Datacenter in Würzburg. Absolute timing necessary for an accurate source tracking will be achived by a GPS clock.

Mount and Drive The present mount is used. Only smaller changes for safety, corrosion protection, cable ducts, etc. is needed. For movement motors, shaft encoders and control electronics have to be bought. The drive system should allow for relatively fast repositioning for three reasons:

- Fast movement is in most cases mandatory for future ToO observations.
- Wobble-mode observations will be done changing the wobble-position continuously (each 20 min) for symmetry reasons.
- To ensure good time coverage of more than one source visible at the same the observed source will be changed in constant time intervals (∼20min).

Therefore three 150 Watt servo motors are intended. A microcontroller based motion control unit (SPS) similar to the one of the current MAGIC II drive system will be used. For communication with the readout-system a standard Ethernet connection based on the TCP/IP-protocol is applied.

Mirrors The existing mirrors are replaced by new plastic mirrors. The cheap and light-weight material has formerly been used for Winston cones flown in balloon experiments. The mirrors are copied from a master, coated with a reflecting and a protective material. By a change of the mirror geometry the mirror area can be increased from 8.5 m^2 to 13 m^2; this includes an increase of $\sim$10% per mirror by using a hexagonal layout. To keep track of the alignment, reflectivity and optical quality of the individual mirrors, and the point-spread function of the total mirror, during long-term observations the application of an automatic mirror adjustment system, as successfully operated on the MAGIC telescope, is intended.

Pointing calibration To correct for axis misalignments a pointing correction algorithm as used in the MAGIC tracking system will be applied. It is calibrated by measuring the reflection of bright guide stars on the camera surface and ensures a pointing accuracy well below the pixel diameter. Therefore a high sensitive low-cost video camera, as already in operation for MAGIC I and II, will be installed.

PM Gain calibration For the calibration of the PM gain a calibration system as used for the MAGIC telescope is build.

Conclusion The setup of a small telescope dedicated for long-term AGN monitoring is easily feasible. Such an activity is motivated by a variety of physical questions to be answered by the integration of this instrument in multiwavelength observations.

Future extensions The known duty cycle of 10% (∼1000h/year) for a Cherenkov telescope operated at La Palma limits the time-coverage of the observations. Therefore we propose a worldwide network of ($<$ 10) small scale Cherenkov telescopes to be build in the future allowing 24h monitoring of the bright AGNs. Such a system is so far completely unique in this energy range.

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